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The Portuguese Guitar Acoustics: Part 1 – Vibroacoustic Measurements

O. Inácio[a], F. Santiago[b] and P. Caldeira Cabral[c]

[a] *Laboratório de Acústica Musical, Escola Superior de Música e Artes do Espectáculo do IPP, Rua da Alegria 503, 4000-045 Porto, Portugal, OctavioInacio@esmae-ipp.pt*
[b] *santiago99@clix.pt*
[c] *pccabral@clix.pt*

ABSTRACT: From the variety of musical instruments that have enriched the history of Portuguese musical culture, the Portuguese Guitar is the one of the few to reach the status of national symbol. There are two distinct types of this instrument – the Lisbon and the Coimbra guitar – named after the towns where the two different styles of fado have developed. These models differ basically on their size and tuning, both comprising 6 courses of double steel strings, while the construction method (strutting patterns, wood species used and soundboard thickness distribution) varies for different builders. Although this instrument deserved the attention of a few researchers in the ethnological and musicological perspective, no thorough scientific study of the vibroacoustic behaviour of these instruments has been published so far. This paper is the first on an ongoing research in this field. Here we present the results of an experimental modal identification performed on the soundboard of fully-assembled Lisbon and Coimbra guitars. We compare and describe the frequency response curves for several specimens as well as their significant vibratory modes. Additionally, this work also aims to set an objective basis for the sound quality evaluation of different instruments presented in a companion paper.

1. INTRODUCTION

Plucked string instruments have been the subject of scientific research for several decades. Among this family of instruments, guitars have received particular attention, whether for its widespread use around the world or the sound quality of its mellow tone, but also because their individual components can generally be studied as linear systems for normal amplitude vibrations of the strings and of the resonating body. Nonetheless, the complexity of the dynamical coupling between its mechanical components and with the surrounding environment still leave several questions unanswered. Consequently, for the last decades, numerous studies have flourished throughout the musical acoustics scientific community, ranging from experimental modal analysis to numerical simulations of instrument sound [1].

Other instruments of this family such as lutes, mandolins or harps, however, lack such in depth studies and apart from current research on the modal characteristics of their resonating bodies – see [2] – very few studies have tried to decipher the adequate construction characteristics that give origin to excellent quality instruments.

Being an instrument virtually only used in Portugal, the Portuguese guitar suffers from this deficiency in research. Fortunately, decades of craftsmanship refinement have provided us with Portuguese guitars of excellent quality, and although still unknown to a great part of the musical world, its sonority, timbre and dynamical range keep seducing most of its new listeners.

While from the ethnological and musicological perspective this instrument deserved the attention of a few researchers [3, 4], no thorough scientific study of the vibroacoustic dynamics of these instruments has been published so far. This paper is the first on an ongoing research in this field. Here we present the results of an experimental modal identification performed on the soundboard of fully-assembled Lisbon and Coimbra guitars. We compare and describe frequency response curves for several specimens as well as some significant vibratory modes. This analysis was also performed with the aim of establishing an *objective* basis for a *subjective* sound quality evaluation of different instruments presented in a companion paper. We begin by a short account of the historical evolution of this instrument and its relation with Portuguese musical culture, moving then to the study of the instruments vibroacoustic characteristics focusing in the low frequency range.

2. THE PORTUGUESE GUITAR (CITHARA LUSITANICA)

2.1 Origins

The instrument we now call the Portuguese guitar was known until the nineteenth century throughout Europe as *Cítara or Citra* (Portugal and Spain), *Cetra and Cetera* (Italy and Corsica), *Cistre* (France), *Cittern and Citharn* (British Isles), *Zither and Zitharen* (Germany and Low Countries).

Directly descended from the Renaissance European *Cittern* derived in turn from the medieval *Citole*, the Portuguese guitar as we know it underwent considerable technical modifications in the last century (dimensions, mechanical tuning system, etc.) although it has kept the same number of 6 double courses, the string tuning and the finger plucking technique characteristic of this type of instrument which is named *dedilho,* meaning the use of the fore finger nail upwards and downwards, as a plectrum.

There is evidence of its use in Portugal since the thirteenth century (*Cítole*) amongst troubadour and minstrel circles and in the Renaissance period, although initially it was restricted to noblemen in court circles. Later its use became popular and references have been found to citterns being played in the theatre, in taverns and barbershops in the seventeenth and eighteenth century in particular. In 1582, Friar Phillipe de Caverell visited Lisbon and described its customs; he mentions the Portuguese people's love for the cittern and other musical instruments.

In 1649 was published the catalogue of the Royal Music Library of King John IV of Portugal containing the best known books of cittern music from foreign composers of the sixteenth and seventeenth centuries, in which the complexity and technical difficulty of the pieces allow us to believe that we had highly skilled players in Portugal. In the first half of the eighteenth century, Ribeiro Sanches (1699-1783) had cittern lessons in the town of Guarda as he mentions in his diary. In the same period there is further evidence to the use of the cittern alluding to a repertoire of sonatas, minuets, etc. shared with other instruments such as the harpsichord or the guitar.

Later in the century (ca. 1750), the so-called “English” guitar made its appearance in Portugal. It was a type of cittern locally modified by German, English, Scottish and Dutch makers and enthusiastically greeted by the new mercantile bourgeoisie of the city of Porto who used it in

the domestic context of *Hausmusik* practice. This consisted of the *"languid Modinhas"*, the *"lingering Minuets"* and the *"risqué Lunduns"*, as they were then called. The use of this type of Guitar never became widespread. It disappeared in the second half of the nineteenth century when the popular version of the cittern came into fashion again by its association with the Lisbon song (*Fado*) accompaniment.
We find the last detailed reference to the *Cítara* in 1858 in the book of J.F.Fètis "The Music Made Easy". The Portuguese translation includes a glossary describing the various characteristics (tunings, social status, repertoire, etc.) of both cittern and "English" guitar of the time.
Nowadays, the Portuguese guitar became fashionable for solo music as well as accompaniment and its wide repertoire is often presented in concert halls and in the context of classical and world music festivals all around the world. [4]

2.1 Types and characteristics

There are basically two models of this instrument: the Coimbra and the Lisbon guitars, named after the towns where the two different styles of *Fado* have developed. However, a few guitars can still be found with slightly different characteristics which are known as Porto guitars (see Figure 1).
The most distinguishable characteristic of the Portuguese guitar is the pear shaped body and the head which exhibits tear-shaped (Coimbra model) or spiral-shaped (Lisbon model) decorations. The top plate (soundboard) can be slightly curved while the back plate is usually flat, both parts are joined by ribs and run roughly parallel to each other. The sound hole is round and typically decorated with pearl-shell infills. The 6 courses of double strings are stretched from the nut to the *atadilho* (a small tailpiece at the end of the body of the instrument) passing over the bridge which is simple placed between the strings and the soundboard. The main characteristics that distinguish the different types of guitars are mainly concerned with the sizes and tunings. Lisbon guitars have an effective string length of 440-445 mm while in Coimbra and Porto guitars this length is usually 470 mm [5].

a) b) c)

Figure 1 – *Portuguese guitars: a) Lisbon, b) Coimbra and c) Porto models.*

3. EXPERIMENTAL PROCEDURE

In order to have a representative sample of the broad range of sound qualities that these instruments may exhibit, vibration and acoustical measurements were performed on 10 different instruments. These instruments vary on the type (Lisbon, Coimbra or Porto), builder and year of construction as well as on the materials of the top (soundboard) and back plate. Table 1 describes the main characteristics of the instruments used in the experiments.

Table 1 – *Description of the guitars used in the experiments*

Guitar	Construction year	Builder	Type	Top plate	Back plate
A	1998	Fernando Meireles	Coimbra	Picea Abies	Dalbergia latifolia
B	1971	Gilberto Grácio	Coimbra	Picea Abies	Dalbergia nigra
C	1969	Gilberto Grácio	Coimbra	Picea Abies	Juglans nigra
D	1990	Gilberto Grácio	Coimbra	Picea Abies	Dalbergia latifolia
E	1920	António Duarte	Porto	Picea Abies	Dalbergia nigra
F	1964	João P. Grácio	Lisbon	Picea Abies	Dalbergia nigra
G	1950	Francisco Silva	Lisbon	Picea Abies	Juglans regia
H	1925	João Grácio Júnior	Lisbon	Picea Abies	Dalbergia nigra
I	1903	Augusto Vieira	Lisbon	Picea Abies	Dalbergia nigra
J	1966	Joaquim Grácio	Lisbon	Picea Abies	Dalbergia nigra

To enable a relevant comparison between the modal characteristics of the different instruments, accelerance frequency response functions, $H_V(\omega) = \ddot{Y}_r(\omega)/F_e(\omega)$, were measured using impact excitation, $F_e(\omega)$, applied perpendicularly to the soundboard at four locations common to all the instruments. The acceleration response, $\ddot{Y}_r(\omega)$, was measured by a light-weight accelerometer placed on the soundboard close to the lower string side of the bridge. Simultaneously, vibroacoustic transfer functions, $H_a(\omega) = p_r(\omega)/F_e(\omega)$, were measured using the same excitation signal, $F_e(\omega)$, while the response, $p_r(\omega)$, was measured by a microphone facing the instrument at approximately 0.5 m distance.

The instrument was placed inside a highly sound absorbing chamber and suspended from a rigid structure by means of rubber bands. The strings were properly tuned and dampened by a textile or plastic material on each side of the bridge.

A full experimental modal identification, based on impact testing, was also performed on one of the instruments. A mesh of 114 impact locations was defined, covering both the soundboard and the fingerboard in order to identify possible coupled motions. The response was measured near the bridge at the same point as previously described. However, some points on the soundboard were impossible to reach with the impact hammer, namely beneath the strings on both sides of the bridge. For these locations, the excitation and response were taken at the reciprocal positions, i.e., impact at the bridge and the accelerometer position at the mesh point where the excitation should be imposed.

The experimental setup used for all the experiments is depicted in Figure 2. Modal identification was achieved by application of a MDOF algorithm in the time domain using a Least Squares Complex Exponential Method [6].

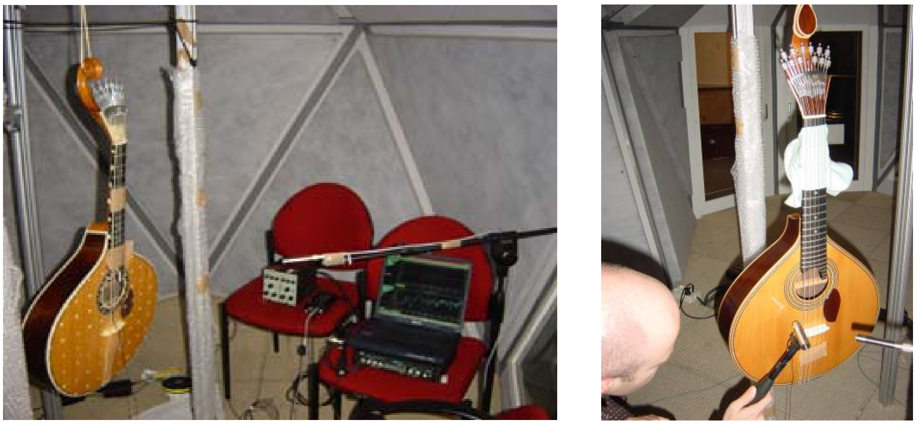


Figure 2 – *Experimental setup showing the impact test positions and the location of the microphone for the vibroacoustic transfer functions measurements.*

4. RESULTS

Figure 3 shows a typical accelerance frequency response function (FRF) and the corresponding vibroacoustic transfer function for guitar E, with impact location at the lower string end of the bridge. The acceleration response is measured at approximately the same location but on the guitar soundboard. The sound pressure response is measured at 0.5 m from the front of the instrument as described before. The accelerance FRF shows a first peak below 100 Hz, which does not contribute considerably to the radiated sound, as can be seen from comparison with the vibroacoustic FRF. Up to 500 Hz the response of the guitar is dominated by modes with lower damping factors than in the higher frequency range where separate modes become much more difficult to distinguish.

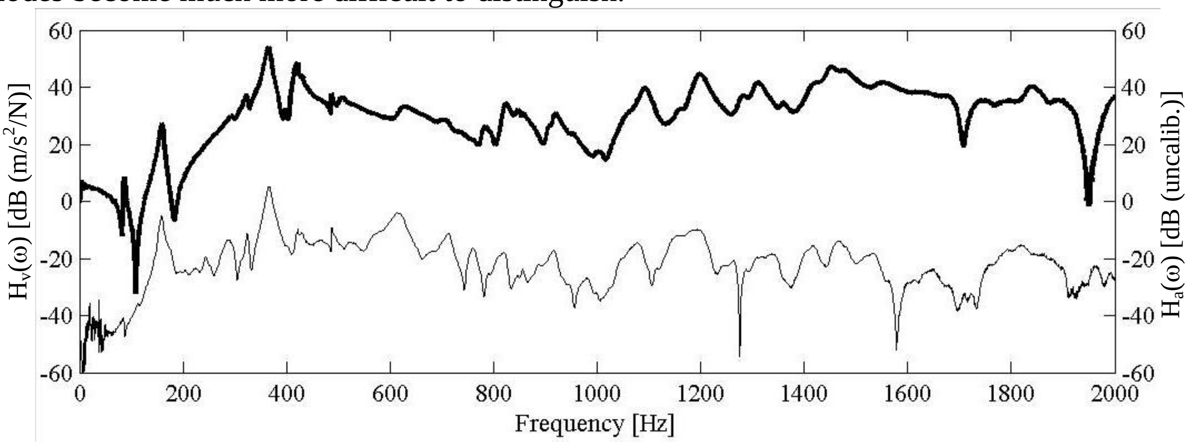


Figure 3 – *Example of an accelerance (heavy line) and vibroacoustic (thin line) frequency response function of guitar E.*

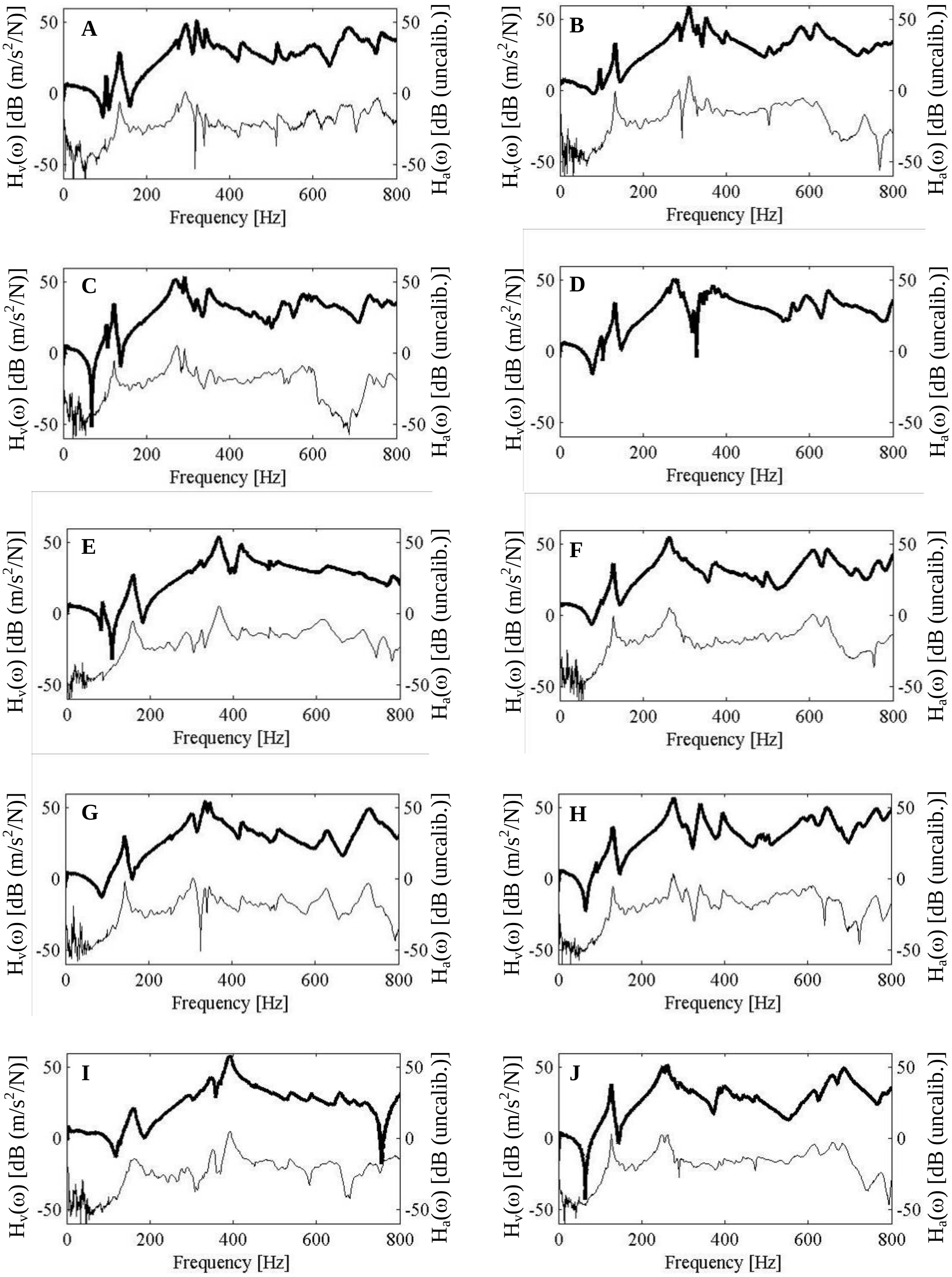


Figure 4 – *Accelerance (heavy line) and vibroacoustic (thin line) frequency response function for guitars A to J in the frequency range of 0-800 Hz.*

Figure 4 depicts the accelerance and vibroacoustic frequency response functions for the 10 guitars for excitation and response locations as in Figure 3. For the first 5 guitars (A-E) there are only two resonances below 200 Hz, where the first one (at approximately 100 Hz) does not radiate sound efficiently, and could be due to a coupled motion between the fingerboard and the body, phenomena which is also found in classical guitars [7]. Interestingly, this first structural resonance is not so apparent in Lisbon guitars (F-J). The second resonance, however, is present in all guitars and is responsible for an important part of the radiated sound spectrum. Due to its low frequency (ranging from 121 Hz to 160 Hz) and its radiation efficiency it was suspected that this resonance could be due to the well known air cavity mode that occurs inside the body of most string instruments with a hollow resonator [8]. In order to identify this also called Helmholtz resonance, a piece of foam was placed over the sound hole, cancelling any possible air oscillations through it. Figure 5 shows a comparison between the accelerance FRF measured with and without the foam for the same points of excitation and response. The red line (with foam) shows the disappearance of a resonance at approximately 130 Hz in comparison with the black line (without foam). This is also apparent in the vibroacoustic FRF shown at the lower part of the plot, which proves that this acoustical resonance is coupled to a structural resonance of the body at the same frequency, as also verified in classical guitars [9]. This phenomenon was found for all the guitars studied.

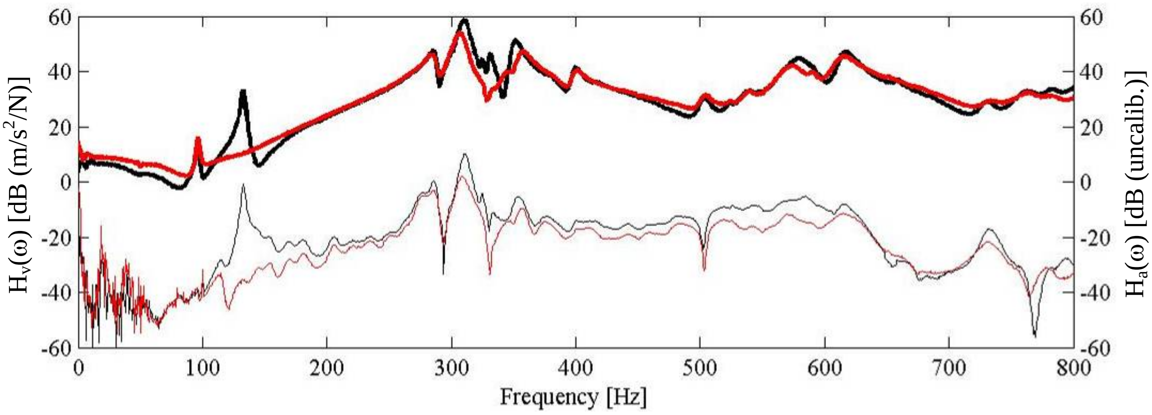
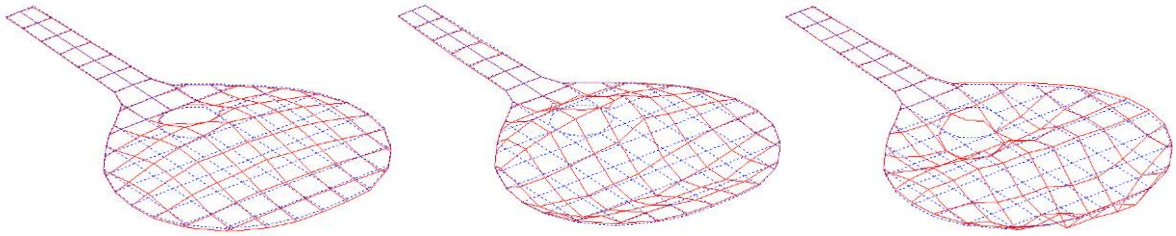


Figure 5 – *Accelerance (heavy lines) and vibroacoustic (thin lines) frequency response function for guitars A to J in the frequency range of 0-800 Hz.*



$f_{(0,0)}$ = 275 Hz $f_{(0,1)}$ = 360 Hz $f_{(0,2)}$ = 635 Hz

Figure 6 – *Modeshapes of three resonances of the soundboard of guitar D.*

Between 250 Hz and 450 Hz there is at least one major resonance or group of resonances which are responsible for a significant part of the radiated spectrum. The most important of these is the (0,0) monopole mode, shown in Figure 6 for guitar D, which radiates sound more efficiently, in contrast with the (0,1) longitudinal dipole mode where adjacent antinodes move in anti-phase and eliminate any net volume flow [9]. For guitar D, the (0,2) longitudinal tripole mode shows up only at 635 Hz. Other modeshapes were also identified and will be reported elsewhere.

5. CONCLUSIONS

In this work we have taken the first steps of an ongoing project to study the vibratory and acoustical characteristics of the Portuguese guitar. The measurement of accelerance and vibroacoustic transfer functions on the soundboard of a set of 10 guitars allowed the recognition of a characteristic frequency range below 200 Hz where one resonance, the air cavity mode, is responsible for the low frequency character of the radiated spectrum. This resonance is accompanied by an acoustically inefficient structural mode which is more apparent in Coimbra guitars relatively to the Lisbon model.

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